Field Plate Load Test to Investigate Stress Distribution in Soil Mass with and without Reinforcement - United Arab Emirates

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ABSTRACT

Strengthening of geogrid reinforcement of weaker soil for foundations is an established method for improving the bearing capacity and load-settlement characteristics of the soil. Plate load tests were performed in outdoor test pits excavated in natural ground to a depth of 3B measuring 2 m x 2 m x 1.30 m using a 0.45 m diameter steel plate of 25 mm thickness. The objective of this study is to investigate the effect of geogrid layers in improving the bearing capacity of foundations and decreasing the load transferred to sub-soil layers. Earth pressure cells were used to measure directly the vertical and horizontal stresses at different depths. Results affirmed that the application of geogrid reinforcement could redistribute the applied footing load to a more uniform pattern, hence reducing the stress concentration, which consequently will result in reduced settlement. In addition, the results of model tests indicated that Boussineq model leads to an overestimation of the vertical stresses near the line of action of the load. Furthemore, using one layer of geogrid reinforcement contributes to decreasing the maximum horizontal stress by about 3%-75% at depths 0 - 1B. The maximum effect of geogrid is obtained at a depth of 2/3 B. This decrease becomes even smaller when two or three layers of geogrid are used.

KEYWORDS: Plate load test, Geogrid, Sand, Improvement, Stresses, Ground, Reinforcement.

INTRODUCTION

One of the most significant problems at construction sites is the availability of good quality materials. Moreover, additives are also unavailable or scarce to facilitate the need of construction. Therefore, there are always some obstructions hindering smooth project execution. Due to this reason, engineers are often searching for alternative designs using sub-standard materials, commercial construction aids and innovative design practices. One of the categories of commercial construction aids is geosynthetics, referring to man-made materials from various types of polymer and being used to enhance geotechnical properties of soil. Various types of geosynthetics available in the market are: geotextiles, geogrids, geonets, geofoams, geomembranes, geocomposites,… etc. The polymeric nature of those products makes them suitable for being applied in the soil, where high levels of durability are required. Geosynthetics perform five major functions; namely, separation, reinforcement, filtration, drainage and moisture barrier. One of the categories of geo-synthetics in particular is geogrids, which are used for improving the engineering properties of soil.

Geogrids represent a small, but rapidly growing segment of the geosynthetics area. Rather than being woven, non-woven or knit textile (or textile-like) fabric,

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geogrids are one of plastic types formed into a very open, grid-like configuration. Therefore, they have apertures greater than 1/4" (6 mm) to allow interlocking with surrounding soil, rock, earth and other adjoining materials. In addition, they are often found to be stretched in one or two directions for improved physical properties (Ramteke et al., 2014).

The reinforcement of soil can be achieved by three methods. First is the physical method through vibration, thermo-electricity and freeze and thaw. Second is the mechanical method that makes use of fibrous materials from geosynthetics family. Third is the chemical method which makes use of conventional materials. These materials include enzymes and polymeric resins. Thus, soil reinforcement is often termed to be an old, yet effective method to increase durability of soil.

Binquet and Lee (1975a and b) investigated the mechanisms of using reinforced earth slabs to improve the bearing capacity of granular soils. They modeled tested strip footings on sand foundations and further reinforced them with wide strips cut from household aluminium foil. An analytical method for estimating the increased bearing capacity based on the tests was also presented. Fragaszy and Lawton (1984) also used aluminium reinforcing strips and model strip foundations to study the effects of sand density and length of reinforcing strips on bearing capacity. Several authors have studied strip foundations. But, reinforcement done with different materials, such as: steel bars (Verma and Char, 1986), steel grids (Dawson and Lee, 1988; Abdel-Baki et al., 1993), geotextiles (Das, 1988) and geogrids (Khing et al., 1993; Ismail and Raymond, 1995), has been highly effective in increasing the strength of soil. On the other hand, numerous researchers have adopted the circular square method (Kazerani and Jamnejad, 1987) or rectangular footings (Guido and Christou, 1988; Adams and Collin, 1997; Omar et al., 1993; Yetimoglu et al., 1994) to improve strength and durability of soil.

Omar et al. (1993) conducted laboratory model tests for the ultimate bearing capacity of strip and square foundations supported by sand reinforced with geogrid layers. Based on their model tests, they determined the critical depth of reinforcement and the dimensions of geogrid layers for mobilizing the maximum bearing-capacity ratio. The following conclusions have been obtained from their model test results. (i) For the development of maximum bearing capacity, the effective depth of reinforcement is about 1.43B for square foundations. (ii) Maximum width of reinforcement layers required for mobilization of maximum bearing capacity ratio is about 4.5B for square foundations. (iii) Maximum depth of placement of the first geogrid layer should be less than about 0.33B to take advantage of reinforcement. The influences of foundation size and scale effects have been investigated. They recommended that these findings cannot be directly transported to full-size foundations without additional verification.

Saran et al. (1995) presented a set of results of laboratory scale model footing tests that were conducted to determine the cyclic load resistance of sand beds reinforced with horizontal geogrid sheets. The test results indicated that the total settlement decreases and the bearing capacity increases with the increase in reinforcement size and number of layers. With the inclusion of reinforcing sheets, the coefficient of elastic uniform compression decreases slightly, but this decreased value is valid up to the increased bearing capacity of the reinforced sand bed. There is significant improvement in the damping capacity upon reinforcing the sand bed as indicated by the comparison of the strain energies under the pressure-settlement curves obtained from cyclic plate load tests.

Laboratory reduced-scale model tests were conducted by Shin and Das (2000) to determine the ultimate bearing capacity of a strip foundation supported by medium and dense sand reinforced by multiple geogrid layers. To simplify the outputs of the experiments, scientists decided to use only one type of geogrid and sand. Tests were conducted for surface foundation conditions and for foundations at various depths. The foundation depths were limited to less than the foundation width. Based on the test results, for a given thickness of the reinforcement zone, the bearing capacity ratio increases when the depth of the foundation is greater than zero (i.e., the surface foundation condition).

A study on bearing capacity and compressibility characteristics of cohesive soil, reinforced by geogrid and supporting square footing loads, was conducted by Ghiassian and Jahannia (2004). The lack of adequate frictional resistance between clay and reinforcing elements was compensated by using a thin sand layer (lens) that was encapsulating the geogrid sheet. In this way, tensile forces induced in the geogrid were transferred to the bulk clay medium through the sand particles and soil reinforcement was improved. Experiments were conducted on two sets of specimens; one set with (1 x 1 x 1) m dimensions and footing size of (19 x 19) cm (series A) and the other set with (0.15 x 0.15 x 0.15) m dimensions and footing size of (3.7 x 3.7) cm (series B). The loading systems for the above specimens were stress-controlled and strain-controlled, respectively. All specimens were saturated and presumably loaded under an undrained condition. The results qualitatively confirmed the effectiveness of the sand lens in improving the bearing capacity and settlement characteristics of the model footing. In series A, the maximum increase in the bearing capacity due to the presence of the sand lens was 17%; whereas in series B, the maximum of increase in the bearing capacity due to the presence of the sand lens was 24%. The percentage reductions in the settlement for these results were 30% and 46%, respectively.

Following up the attempts to measure the performance of the soil, Al-Sinaidi and Ali (2006) presented details of an investigation to evaluate the performance of geogrid reinforcement in the soil. For this purpose, model isolated footing load tests were conducted on soil with and without multi-layers of geogrid at different depths below the footing. The load settlement characteristic behaviour for each soil-geogrid configuration was observed. The influences of various selected parameters on the load settlement behaviour were studied and critically appraised for their practical significance. This research is based on the mechanisms of this system using a large-scale model footing for case studies in which geogrid-reinforced soil footing is used for a school project in Saudi Arabia. This site has a very soft and clay/clayey silt soil and large-scale plate loading tests were conducted according to the procedure specified in ASTMD1194. Also, the research presented a successful application in the use of geogrid-reinforcement. The field observations proved that the geogrid-reinforced system creates an enhancement to soft soils and minimizes differential settlement. The geogrid-reinforced system is more economic and attractive and demonstrates superior performance compared with other ground improvement techniques. It is also optimal for rapid construction and/or strict total and differential settlements of the structure and/or a thick and newly placed fill.

This research investigates the effect of geogrid layers in improving the bearing capacity of foundations and decreasing the load transferred to sub-soil layers. Earth pressure cells were used to measure directly the vertical and horizontal stresses at different depths

Laboratory Tests

The site was selected in the United Arab Emirates. Grain size distribution was determined by sieve analysis and hydrometer tests conducted on dune sand samples according to ATTM D 422-00. The grain size distribution curves of the soil sample are shown in Figure 1. The sand of this site is predominantly fine sand with a small amount of non-plastic fines. According to the Unified Soil Classification System, the soil is classified as poorly graded sand (SP).

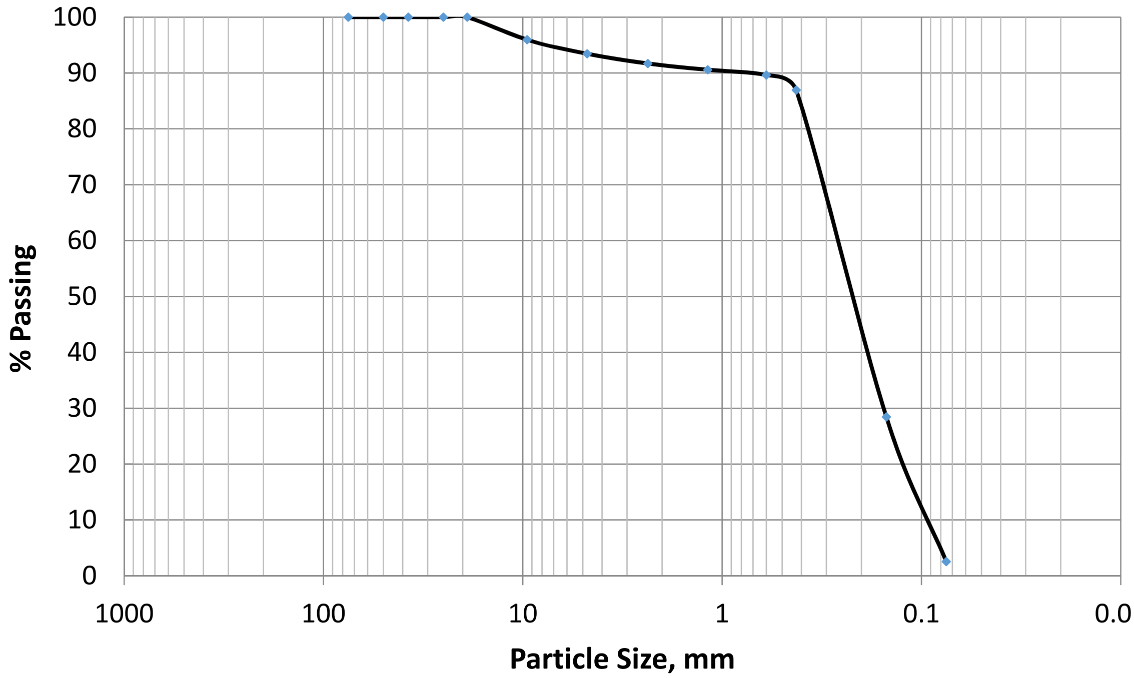


Figure (1): Grain size distribution of the soil in the site

The maximum and minimum densities of sand were determined according to ASTM D4253-00 and ASTM D4254-00, respectively. A modified Proctor compaction test was conducted on the soil according to ASTM D1557-00. Figure 2 shows the density – water content relation as obtained from the compaction test.

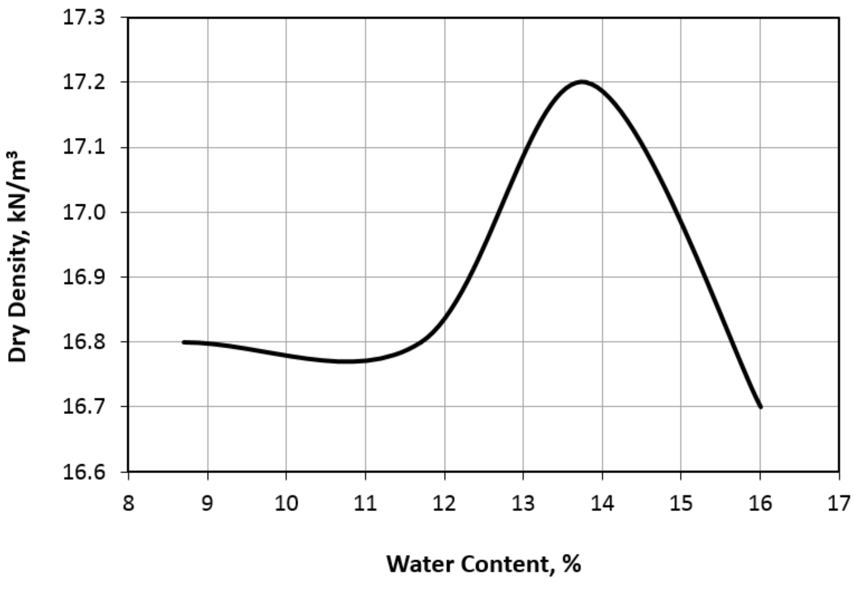


Figure (2): Moisture content-density relationship from modified compaction test

Field Work

In situ field unit weight, γ_{field}, was obtained by the sand-cone method, which is one of the most common field density test methods (ASTM D 1556-00). The moisture content was determined according to (ASTM D 2216-00). Summary of the soil properties is shown in Table 1.

Table 1. Summary of the soil properties

Description	Value
Specific gravity, G_S	2.65
% Gravel	7.0
% Sand	90.0
% Fines	3.0
Coefficient of uniformity, C_U	2.91
Coefficient of curvature, C_C	0.95
Fines' classification, PI	NP
Classification of soil, USCS	SP
Maximum dry unit weight, kN/m^3	1.72
Optimum moisture content, *w*%	13.9
Maximum void ratio, e_{max}	0.78
Minimum void ratio, e_{min}	0.48
Relative density, D_r %	20
Average field dry unit weight, kN/m^3	15.1
Average field moisture content, w%	4.3
Average degree of compaction, R%	88

The plate load test is a semi-direct method to estimate the allowable bearing pressure of soil to induce a given amount of settlement. Plates, round, varying in size from 25cm to 46 cm with a thickness of about 2.5cm, are employed for the test. The load on the plate is applied by making use of a 50-ton hydraulic jack. The reaction of the jack load is taken by a truck. The settlement of the plate is measured by two dial gauges of 0.01 mm sensitivity placed 180° apart. The dial gauges are fixed to an independent support which remains undisturbed during the test. Figure 3 shows the arrangement for a plate load test. The method of performing the test is essentially according to (ASTM D 1196-93).

In spite of shortcomings, load tests are occasionally used. The procedure has been standardized as ASTM D 1196, which is essentially as follows:

[1] Deciding on the type of load application. If it is to be a reaction against piles, they should be driven or installed first to avoid excessive vibration and loosening of the soil in the excavation where the load test will be performed.

[2] Excavating a pit to the depth at which the test is to be performed. The test pit should be at least four times as wide as the plate and to the depth at which the foundation is to be placed. If it is specified that three sizes of plates are to be used for the test, the pit should be large enough, so that there is an available spacing between tests of 3D (D is the plate diameter) of the largest plate.

[3] A load is placed on the plate and settlements are recorded from a dial gauge, accurate to 0.25 mm. Observations on load increment should be taken until the rate of settlement is beyond the capacity of the dial gauge. Load increments should be approximately one-fifth of the estimated bearing capacity of the soil. Time intervals of loading should not be less than 1 hour and should be approximately of the same duration for all the load increments.

[4] The test should continue until a total settlement of 25 mm is obtained or until the capacity of the testing apparatus is reached. After the load is released, the elastic rebound of the soil should be recorded for a period of time at least equal to the time duration of a load increment.

Procedure

Plate loading tests provide a direct measure of compressibility and occasionally of the bearing capacity of soils which are not easily sampled. The technique adopted in this investigation for carrying out the plate loading test has been described by ASTM D1196-93. The procedure followed in this work is as follows:

[1] Test pit area (2 x 2 m) was selected and natural soil was excavated to a depth of 1.30 m. This depth was chosen based on Boussineq stress distribution

theory, where stress below a footing dissipates to effectively zero at a depth of about 3B below the footing.

[2] Plate bearing was carefully centred under the jack assembly. Other plates of lesser diameters were also placed on the centre of the main plate to increase rigidity.

[3] Three dial gauges were attached to the reference beam and fixed over the plate in an appropriate location to indicate the average settlement results.

[4] When the equipment has been properly arranged, pressure was applied to the soil in cumulative equal increments of approximately 90 kPa.

[5] The applied load was held for 10-15 minutes and the dial gauge readings were recorded at an interval of 5 minutes. The same process was done to all of the loading increments reaching maximum load.

[6] The load was released at the same rate above and the readings of dial gauges were recorded, then reloading was done as in the procedure above.

[7] Loading and unloading above are repeated in a repetitive process.

[8] In case of geogrid existence, the same procedure above is followed. Locations of geogrid layers are shown in Figures 4 and 5.

a b c d

Figure (3): Experimental setup for plate load test

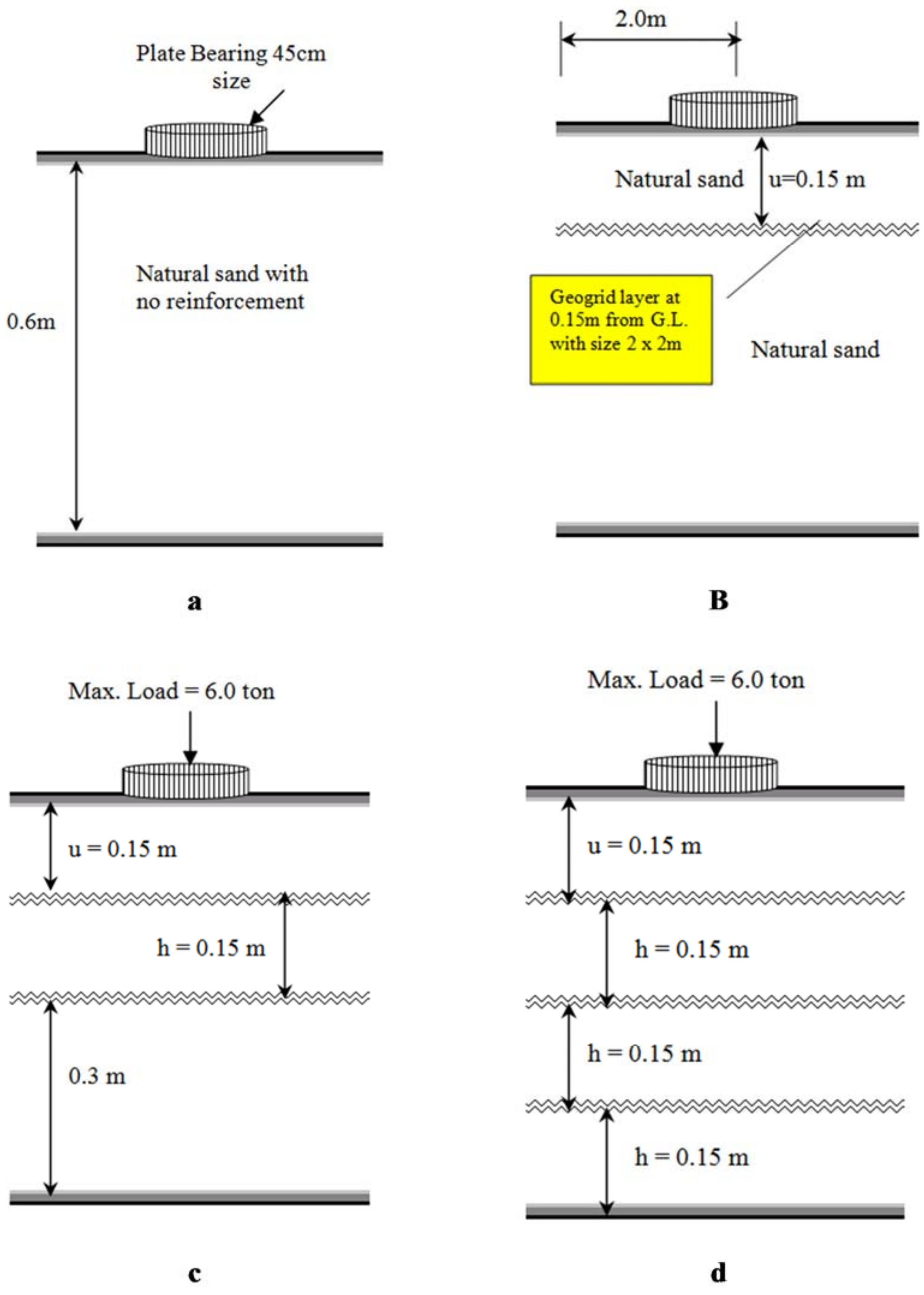
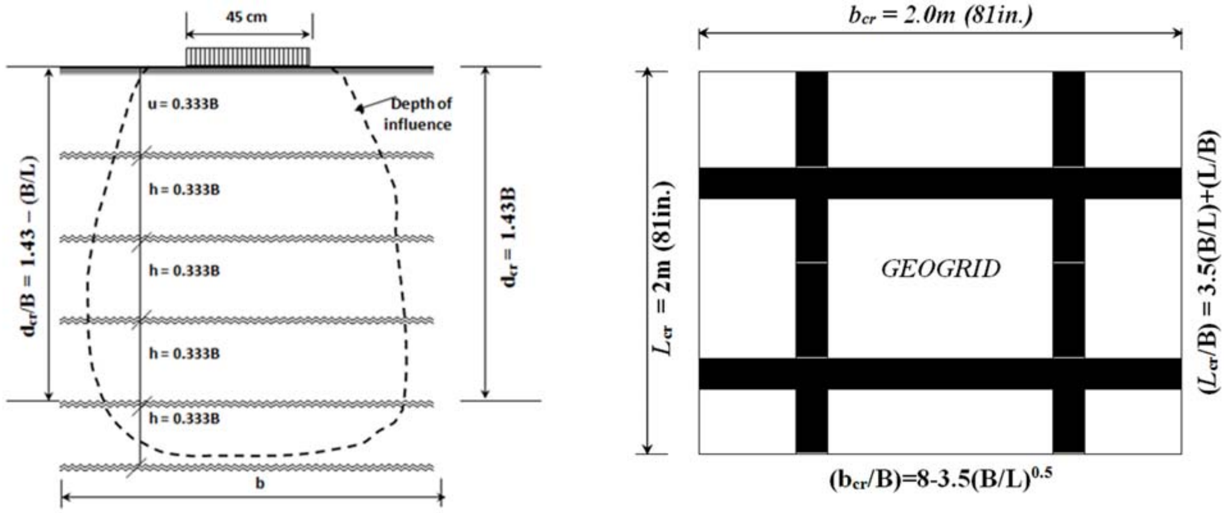


Figure (4): Details of soil layers and layout of reinforcement



a. Profile b. Plan

Figure (5): Depth of influence of geogrid reinforcement

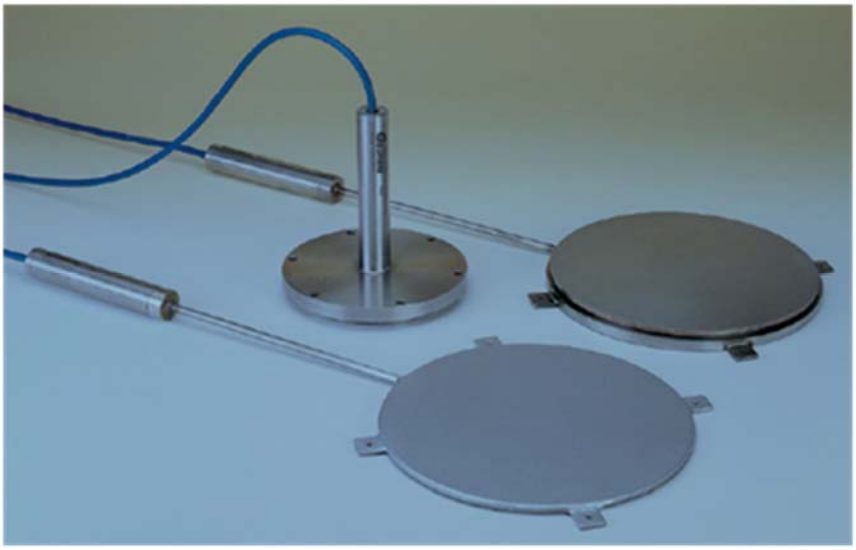


Figure (6): Earth pressure cell model 4800 (Geokon, Inc.)

Figure 6 shows the earth pressure cell Model 4800 (Geokon, Inc., Lebanon, NH) which has been used in this study. Earth pressure cells were constructed from two thin stainless steel plates welded together around their periphery and separated by a narrow gap filled with hydraulic fluid. A length of stainless steel tubing connected the fluid-filled cavity to a pressure transducer that converted the fluid pressure into an electrical signal transmitted by cable to the readout,which was also connected to a computer. Earth pressure cells could be positioned in the fill at different orientations, so that soil pressure could be measured in two or three directions. The Model GK404 read out (Geokon, Inc.) provided six excitation positions (A–F) with a display resolution of 0.1 digit.

RESULTS AND DISCUSSION

Pressure – Settlement Relations

Figure 7 presents the pressure-settlement relationships obtained from different tests at the surface. It is noticed that at a constant pressure value, the settlement decreases as the number of geogrid layers increases. It is also noticed that in all cases, the settlement is reduced by a small amount when the number of geogrid layers increases. In addition, the presence of geogrid layers increases the stiffness of soil-geogrid system and hence the soil mass carries higher stresses.

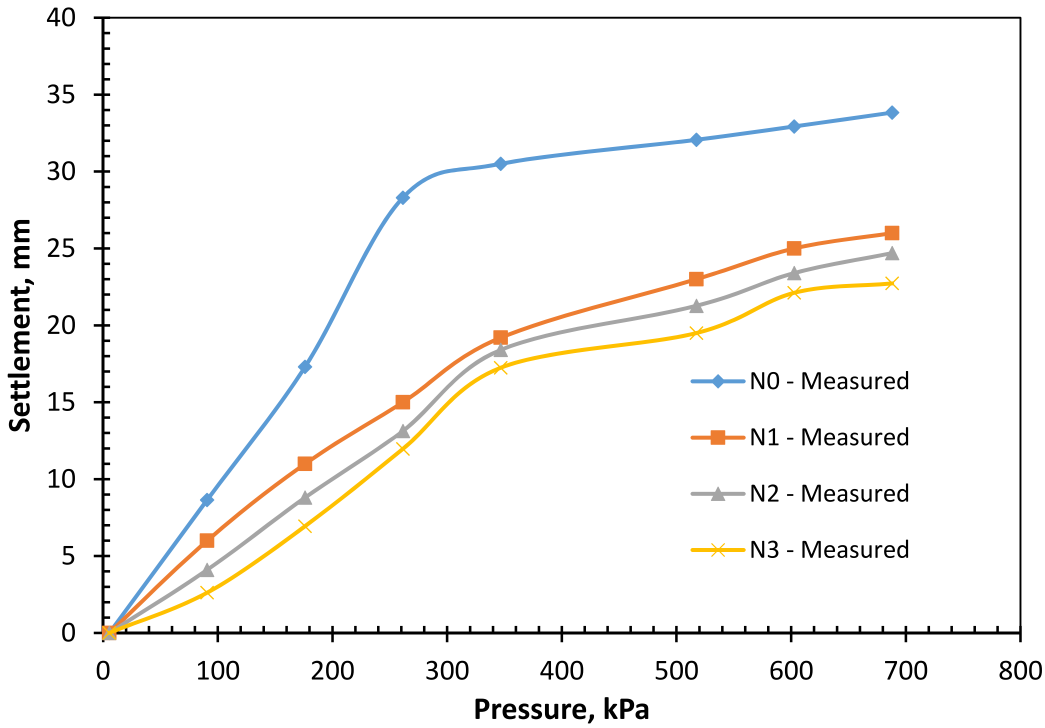


Figure (7): Plate load pressure-settlement response at the surface for unreinforced soil and reinforced soil at different depths

Vertical Stresses under Circular Plate at Different Depths (Measured and Using Boussineq Equation)

Stresses along the vertical axis of symmetry under uniformly loaded circular footing can be given by the equation (Reported by Murthy, 2002):

$$\sigma_z = q\left[1 - \frac{z^3}{\left[R_0^2 + z^2\right]^{3/2}}\right] \quad (1)$$

where: R_o is the radius of the plate (footing).

q is the applied pressure.

z is the depth.

Figures 8 and 9 show a comparison between the measured and calculated values of vertical pressure with depth for a plate loaded under applied pressure of 90.74 kPa and 261.4 kPa, respectively. It is noticed that the measured pressure at any depth increases with the number of geogrid layers. This is due to the increased stiffness of reinforced soil layer with the presence of geogrid.

Geogrid functions in two ways: reinforcement and separation which are the techniques of improving poor soil with geogrid; and increasing the stiffness and load-carrying capacity of the soil through frictional interaction between the soil and the geogrid material. A geogrid-reinforced soil is stronger and stiffer and gives more strength than the equivalent soil without geogrid reinforcement. Geogrid provides improved aggregate interlock in stabilizing road infrastructure through sub-base restraint reinforcement applications. Geogrid reinforcement provided between the base course and sub-grade soil carries the shear stress induced by vehicular loads.

Geogrid mesh provides better interlocking with the soil particles, thus ensuring adequate anchorage during loading. The improvement in the load-carrying capacity could be attributed to improved load dispersion through reinforced sub-base onto the sub-grade. This, in turn, results in lesser intensity of stresses getting transferred to sub-grade, thus leading to lesser sub-grade distress.

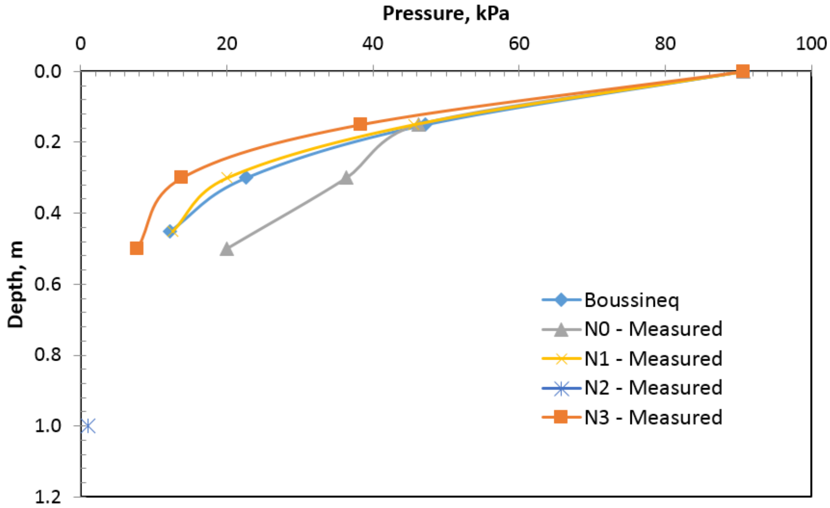


Figure (8): Comparison between measured and calculated vertical pressures at different depths (applied pressure = 90.74 kPa)

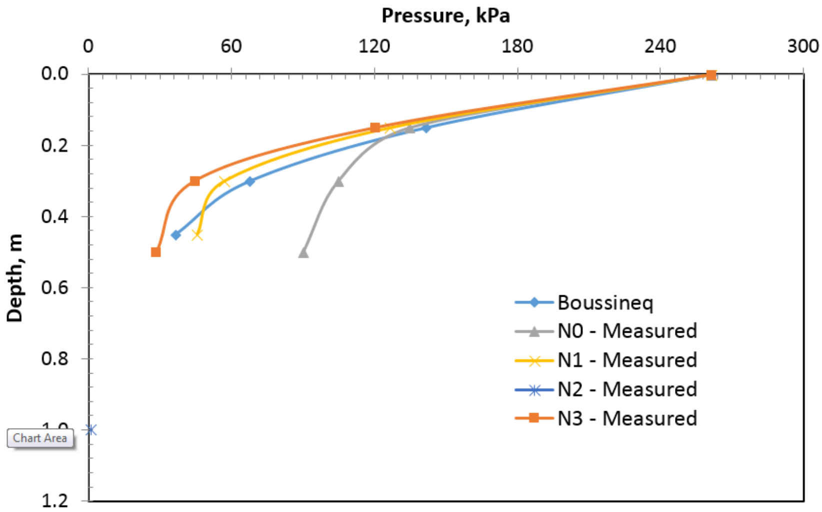


Figure (9): Comparison between measured and calculated vertical pressures at different depths (applied pressure = 261.4 kPa)

Due to better particle-geogrid interlock, vertical stresses in sand decrease when the geogrid is placed in one layer in comparison to unreinforced sand. The reduced vertical stresses in the sand in case of geogrid-reinforced sand also imply a subsequent reduction in the sub-grade stresses. This signifies the role of reinforcement in dissipating the applied vertical stresses to an acceptable level at the sub-grade soil. Therefore, this can be an observation that is particularly important in the case of structures to be constructed on soft soils. In essence, the geogrid reinforcement of soil would transform a portion of the applied vertical stress that otherwise would be transferred to the sub-grade soil, towards increasing the confining pressure on the soil, thereby enhancing the structure stability.

Stresses in Horizontal Plane at Different Depths (Measured and Using Boussineq)

The stress increase, $\Delta\sigma_z$, at any point below a uniformly loaded circular area was calculated by the following equation given by Ahlvin and Ulery (1962):

$$\Delta\sigma_z = q(A' + B') \tag{2}$$

A' and B' are functions of z/R and r/R. These functions are presented as tables and reported by Das (2014);

where: R is the radius of the plate (footing).

r is the distance from the centre of the loaded area.
q is the applied pressure.
z is the depth.

Figures 10 to 12 show comparisons between the measured and calculated horizontal stresses at different depths and distances from the centre of the plate. It is noticed that in all cases, the horizontal stress is maximum under the plate centre. On the other hand, there is a considerable decrease in the horizontal stress and the value at the edge of the plate is about 50% of the maximum stress. The horizontal stress decreases to about 10% of its maximum value at a distance of about B (plate diameter) from the plate centre.

There is a considerable difference between the actual (measured) horizontal stresses and the calculated ones. This means that Boussineq equations provide overvalues for stresses. Shear stress developed between the sand and the geogrid provides an increase in lateral confining stress within the base. Granular materials generally exhibit an increase in elastic modulus with increased confining stress. The second sand reinforcement component results from an increase in stiffness of the sand, when adequate interaction develops between the sand and the geosynthetics. The increased stiffness of this layer results in lower vertical strains in the base. An increase in modulus of the base would also be expected to result in lower dynamic, recoverable vertical deformations of the roadway surface, implying that fatigue of the asphalt concrete layer would be reduced. Models of reinforcement relying upon an increase in confinement and modulus of the base include those proposed by Kinney et al. (1998) and Sellmeijer (1990).

Using one layer of geogrid reinforcement contributes to decreasing the maximum horizontal stress by about 3%-75% at depths 0 - 1B. The maximum effect of geogrid is obtained at a depth of 2/3 B. This decrease becomes even smaller when two or three layers of geogrid are used.

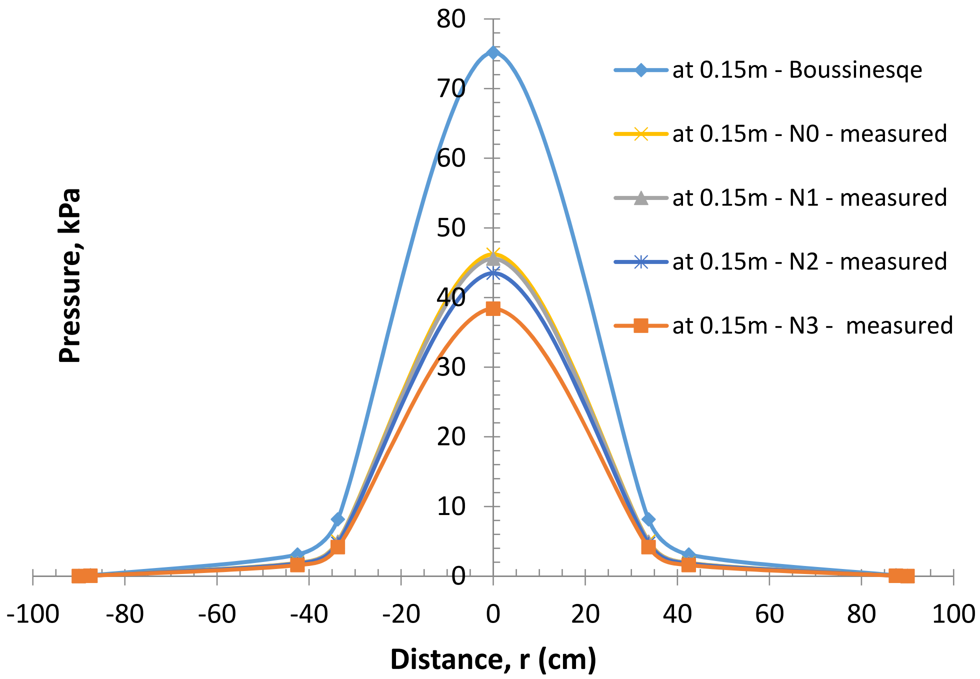


Figure (10): Comparison between measured and calculated stresses (using Boussineq) in horizontal plane at a depth of 0.15 m of unreinforced and reinforced soil (applied pressure = 90.7 kPa)

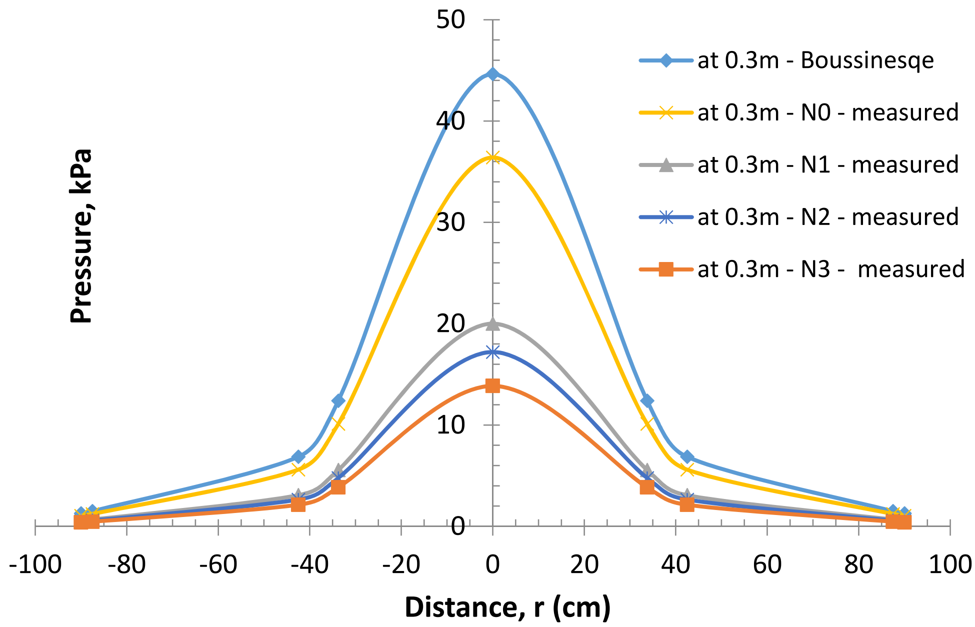


Figure (11): Comparison between measured and calculated stresses (using Boussineq) in horizontal plane at a depth of 0.30 m of unreinforced soil and reinforced soil (applied pressure = 90.7 kPa)

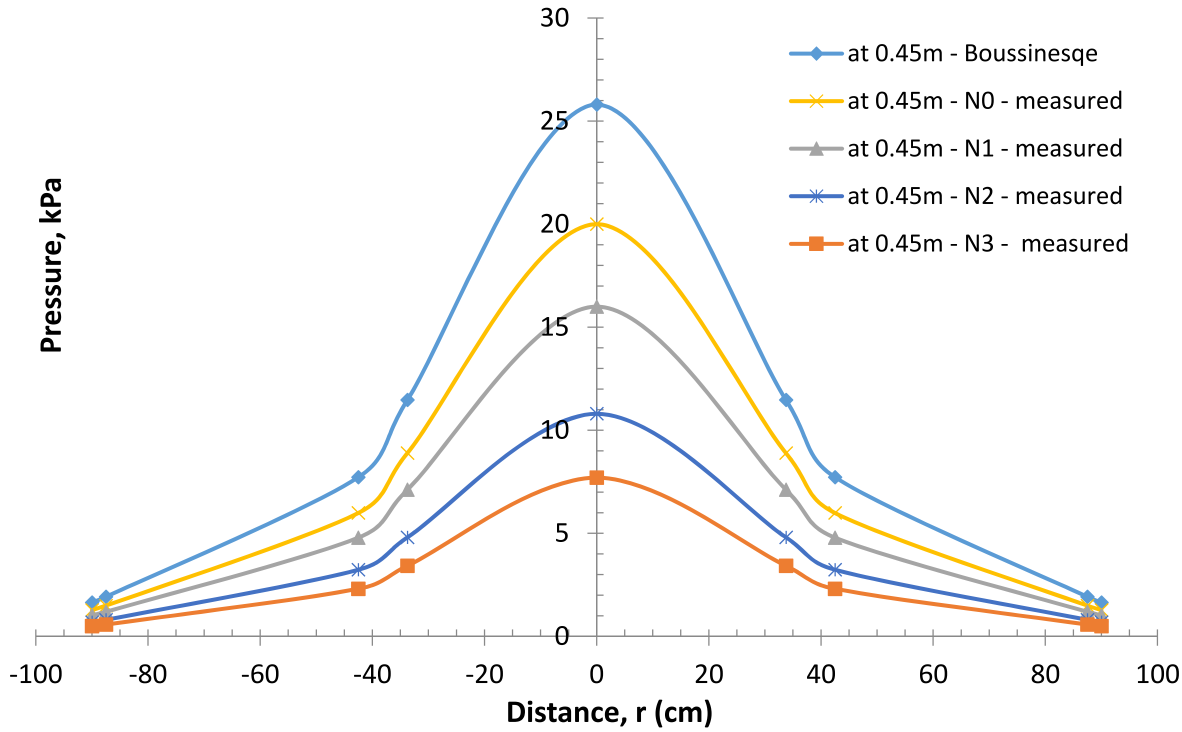


Figure (12): Comparison between measured and calculated stresses (using Boussineq) in horizontal plane at a depth of 0.45 m of unreinforced soil and reinforced soil (applied pressure = 90.7 kPa)

CONCLUSION

It has been inferred that the values of stress tend to decrease as geogrid layers are added. Moreover, the decrease may be somewhat to be depending on the increasing number of geogrid layers. In addition, the pressure-intensity range for the reinforced sand bed is much higher as compared to the pressure-intensity range for the unreinforced sand. This increase may perhaps be attributed to dilating of the sand layers around the reinforcements as well as to the flexibility of the reinforcements. In addition, the results of model tests indicated that Boussineq model leads to an overestimation of vertical stresses near the line of action of the load. Finally, using one layer of geogrid reinforcement contributes to reduce the maximum horizontal stress by around 3%-75% with varying depths of 0 – 1B. However, the maximum effect of the geogrid has been obtained at the depth of 2/3 B. Therefore, the decrease becomes smaller after the usage of 2-3 geogrid layers.

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